Mine Gases

U. S. Department of Labor
Mine Safety and Health Administration
National Mine Health and Safety Academy

Safety Manual No. 2

Revised 1999

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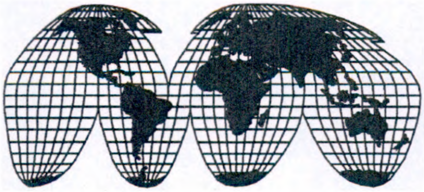

Mine Gases

U. S. Department of Labor
Alexis M. Herman
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Mine Safety and Health Administration
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Assistant Secretary

Safety Manual No. 2

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PREFACE

This is one of a series of manuals prepared by the technical staff of the Mine Safety and Health Administration (MSHA) to acquaint the reader with a specific area of mining. Each deals with a single topic and is designated for use by miners, students, and others interested in additional information on topics discussed in this series. This manual deals with the gases found in mines.

The front cover shows an early carbon monoxide detector – the canary. While not used for this purpose today, it remains as a symbol of the miner's early attempts to locate an inexpensive, portable detector that would warn of the presence of carbon monoxide.

Other manuals available in this series are listed on the inside back cover. Multiple copies may be ordered for $2.00 each. Single copies of safety manuals may be obtained free of charge from:

National Mine Health and Safety Academy
Instructional Materials Department
1301 Airport Road
Beaver, WV 25813-9426
Phone: 304-256-3257

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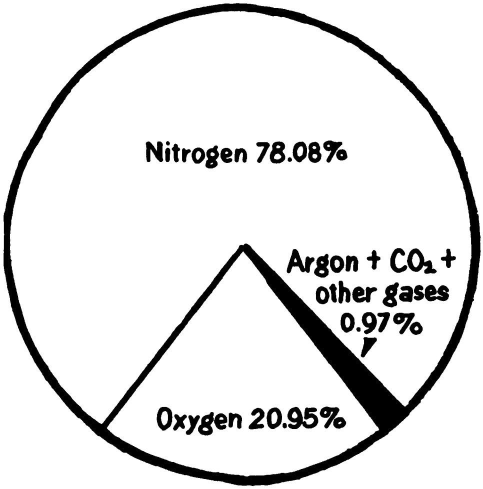


Air is a mixture of gases. Clean, dry air contains about 78.08 volume percent nitrogen, 20.95 volume percent oxygen, and 0.97 volume percent argon, carbon dioxide, and other gases.

SOURCES AND PROPERTIES OF MINES GASES

Air

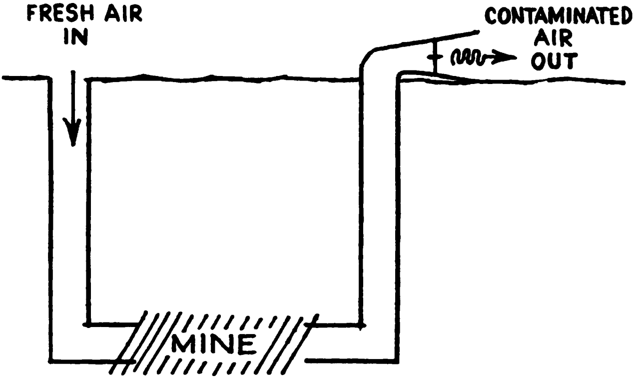
The air found in operating mines supplies the oxygen needed by those who go underground. It also removes the undesirable gases and dust produced during mining. In deep mines, it may be used to remove heat and to cool the miners.

Air is a mixture of gases. Its composition may vary slightly from one location to another. However, clean, dry air near sea level contains the gases listed in Table 1. In nature, of course, air is not always dry but contains 0.1 to 3 percent water vapor. The amount depends on the temperature and the relative humidity.

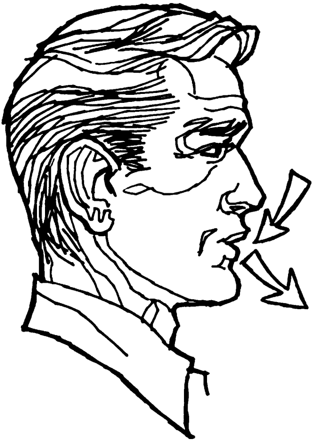
TABLE 1
Composition of Clean, Dry Air at Sea Level
(U.S. Standard Atmosphere)

Gas	Symbol	Volume %[1]
Nitrogen	N_2	78.08
Oxygen	O_2	20.95
Argon	Ar	0.93
Carbon Dioxide	CO_2	0.03
Other[2]	-	0.01

[1] Cubic feet of gas in 100 cubic feet of air.
[2] Includes neon, helium, krypton, xenon, methane, nitrous oxide and ozone.



As air passes through a mine, it picks up other gases as well as the dust formed during mining.



20.95% O_2
0.03% CO_2

16% O_2
4% CO_2

Dry inhaled air normally contains 20.95 percent oxygen; exhaled air contains about 16 percent oxygen, 4 percent carbon dioxide and water vapor.

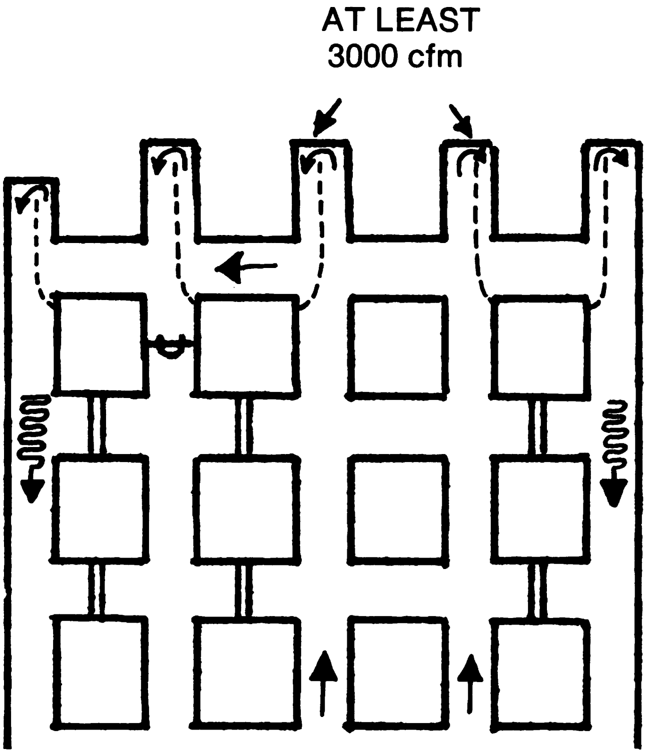
As air passes through a mine, it picks up other gases as well as dust formed during mining. At the same time, air loses oxygen to the mine surroundings and to the people in the mine. For example, oxygen is absorbed by coal, other rocks and timbers, and is also consumed by workers. In addition, during the winter months, because outside air is relatively dry, air picks up moisture. The reverse process occurs in the summer. That is why most mines are drier in the winter and damper in the summer. The amount of oxygen consumed[3] by the people in a mine depends in part on the rate at which they work (Table 2).

TABLE 2 - Approximate Rate and Volume of Respiration and of Oxygen Consumption by Adults

Degree of Activity	Respirations per minute	Air inhaled per respiration, cubic inches	Air inhaled per minute, cubic inches	Oxygen consumed per minute, cubic inches
At Rest	16	30	480	20
Moderate Exercise	30	100	3,000	120
Vigorous Exercise	40	150	6,000	240

[3] Exhaled air contains about 16 percent oxygen and 4 percent carbon dioxide. The actual composition depends on a number of factors including diet and breathing rate.

However, the composition of the air also depends on the rate at which it flows through the mine. Under normal conditions, the flow rate is specified in such a manner that the contaminant gases do not render the air unsafe for human use. The current standards for coal mines are:



Examples of minimum required airflow at mining faces are:

- **At least 3,000 cfm in bituminous or lignite coal mines.**
- **At least 1,500 cfm in anthracite coal mines.**
- **At least 2,000 cfm in Class III noncoal mines.**

All active workings must be ventilated by a current of air containing not less than 19.5 volume per centum of oxygen, not more than 0.5 volume per centum of carbon dioxide, and no harmful quantities of other noxious or poisonous gases. The volume and velocity of the current of air must be sufficient to dilute, render harmless, and to carry away flammable, explosive, noxious, and harmful gases, dusts, smoke, and fumes.

The quantity of air reaching the last open crosscut and reaching the intake end of a pillar line is 9,000 cubic feet per minute in bituminous and lignite mines, and 5,000 cubic feet per minute in anthracite mines. In anthracite mining when robbing areas, where air currents cannot be controlled, the air shall have perceptible movement. Greater amounts of air are required where longwall and shortwall mining units are operating. In Class III metal/nonmetal mines, the quantity of air required in the last open crosscut is 9,000 cubic feet per minute for longwall or continuous mining units, and 6,000 cubic feet per minute for other systems. All these air quantities are minimum amounts and greater quantities may be required on a mine-to-mine basis.

30 CFR 75.322 Harmful quantities of noxious gases.

Concentrations of noxious or poisonous gases, other than carbon dioxide, shall not exceed the threshold limit values (TLV) as specified and applied by the American Conference of Governmental Industrial Hygienists....Detectors or laboratory analysis of mine air samples shall be used to determine the concentrations of harmful, noxious or poisonous gases.

30 CFR 71.700 Inhalation hazards; threshold limit values for gases, dust, fumes, mists, and vapors.

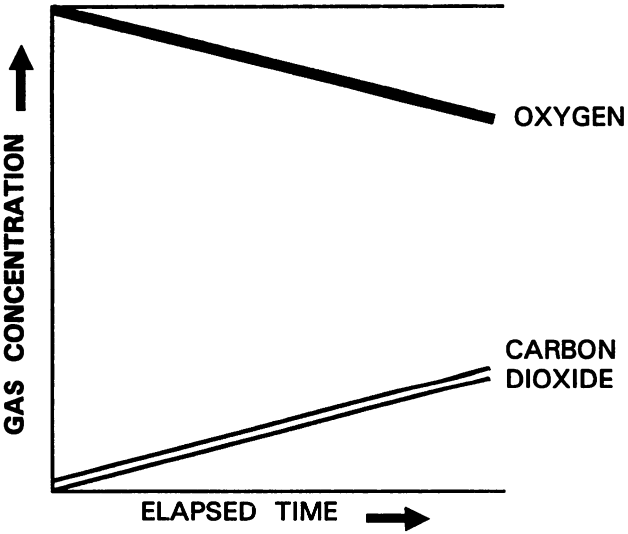
(a) No operator of an underground coal mine and no operator of a surface coal mine may permit any person working at a surface installation or surface worksite to be exposed to airborne contaminants (other than respirable coal mine dust, respirable dust containing quartz, and asbestos dust) in excess of, on the basis of a time-weighted average, the threshold limit values adopted by the American Conference of Governmental Industrial Hygienists in "Threshold Limit Values of Airborne Contaminants" (1972) which is hereby incorporated by reference and made a part hereof. Excursions above the listed threshold limit values shall not be of greater magnitude than is characterized as permissible by the conference. This paragraph does not apply to airborne contaminants given a "C" designation by the conference in the document. This document is available for examination at the Mine Safety and Health Administration, Department of Labor, 4015 Wilson Boulevard, Arlington, VA 22203; at every Coal Mine Health and Safety District and Subdistrict Office; at the National Institute for Occupational Safety and Health, 5600 Fishers Lane, Rockville, MD; and at the Public Health Service Information Centers listed in 45 CFR 5.31. Copies of the document may be purchased from the Secretary-Treasurer, American Conference of Governmental Industrial Hygienists, Post Office Box 1937, Cincinnati, OH 45202.

30 CFR 57.5001 Exposure limits for airborne contaminants.

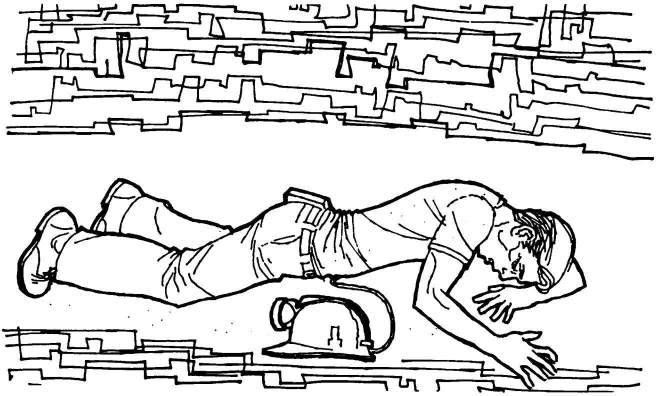
Except as permitted by 30 CFR 57.5005--

(a) Except as provided in paragraph (b), the exposure to airborne contaminants shall not exceed, on the basis of a time weighted average, the threshold limit values adopted by the American Conference of Governmental Industrial Hygienists, as set forth and explained in the 1973 edition of the Conference's publication, entitled "TLV's Threshold Limit Values for Chemical Substances in Workroom Air Adopted by ACGIH for 1973," pages 1 through 54, which are hereby incorporated by reference and made a part hereof. This publication may be obtained from the American Conference of Governmental Industrial Hygienists by writing to the Secretary-Treasurer, P. O. Box 1937, Cincinnati, Ohio 45201, or may be examined in any Metal and Nonmetal Mine Safety and Health District Office of the Mine Safety and Health Administration. Excursions above the listed thresholds shall not be of a greater magnitude than is characterized as permissible by the Conference.

If there were no airflow in a sealed inhabited room, the oxygen level would gradually decrease and the carbon dioxide would increase. The time required to reduce the oxygen content to a dangerous level normally depends on the size of the room and the rate at which the oxygen is used by the miners. For example, a person at rest uses about 0.7 cubic feet of oxygen per hour. In a sealed 1,000 cubic foot room, if there were no provisions to remove exhaled carbon dioxide, a person would experience difficulty in breathing within approximately 30 hours. On the



The oxygen concentration decreases and the carbon dioxide concentration increases in a sealed inhabited room.



An oxygen-deficient atmosphere with an excessive amount of nitrogen will not sustain life.

other hand, a person working vigorously would experience difficulty breathing within about 3 hours.

Contaminant gases are often produced in mines under both normal and abnormal conditions. For example, carbon dioxide is also produced by flame safety lamps, fires, diesel engines, and blasting operations; in some cases, the coal or different ores and the adjacent strata also liberate this gas. Diesel engines, fires, and explosives may also produce carbon monoxide and the oxides of nitrogen. Still other gases (methane, hydrogen sulfide, excess nitrogen, hydrogen, and ethane) are found in some mines. These are discussed in greater detail in the following paragraphs, along with their effects on the human body.

Normally a flame safety lamp will not burn in an atmosphere containing less than about 16 percent oxygen. Miners should not enter such areas.

Nitrogen (N_2)

Nitrogen, which is found in the air and in some rocks, is an inert, colorless, odorless, tasteless gas that is slightly lighter than air. As noted previously, it is the main diluent of oxygen in the air, and when added to air, it produces an oxygen-deficient atmosphere. In any case, if an excessive amount of nitrogen is present (that is, an amount greatly in excess of that normally found in air), an atmosphere will result which cannot sustain life.

Oxygen (O_2)

This gas is important to us because it is needed to support life. It is colorless, odorless, and tasteless, and slightly heavier than air. While we are accustomed to breathing air with about 21 percent oxygen, we can function satisfactorily with lesser or greater amounts. However, when the oxygen content drops below about 16 percent[4], most persons find that their breathing becomes labored.

At oxygen levels below about 10 percent, many people become unconscious. Interestingly, the flame of a safety lamp is extinguished in a methane-free atmosphere containing about 16 percent oxygen. Small amounts of methane tend to decrease this value somewhat (for example, extinction occurs at about 15 percent oxygen when the atmosphere is contaminated with 1 percent methane). In general, however, it is not advisable to enter an area when a flame safety lamp is extinguished.

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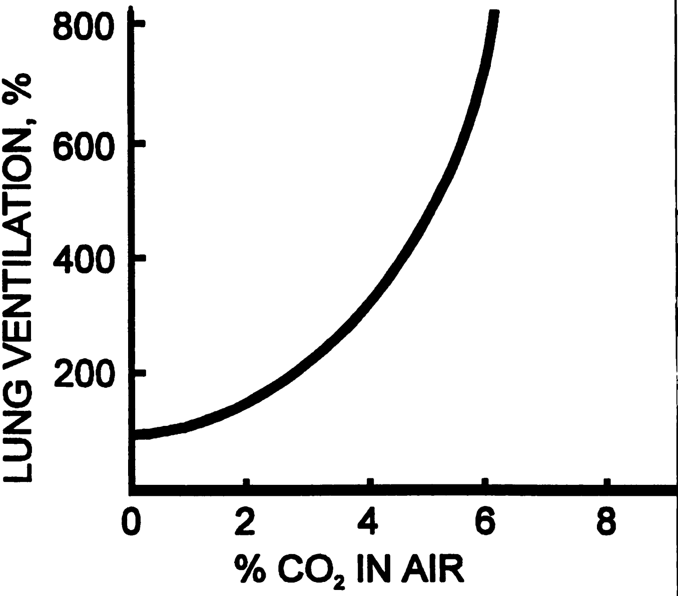
[4] This amount cannot be tolerated if carbon dioxide is the diluent (contaminant) gas.

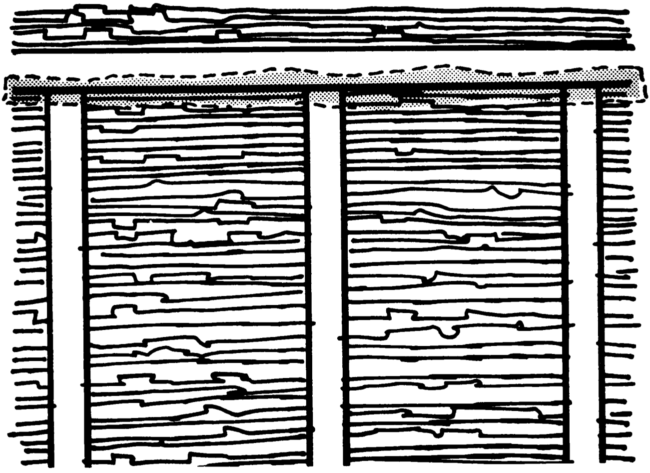


Lung ventilation increases with an increase in the carbon dioxide (CO_2) concentration.

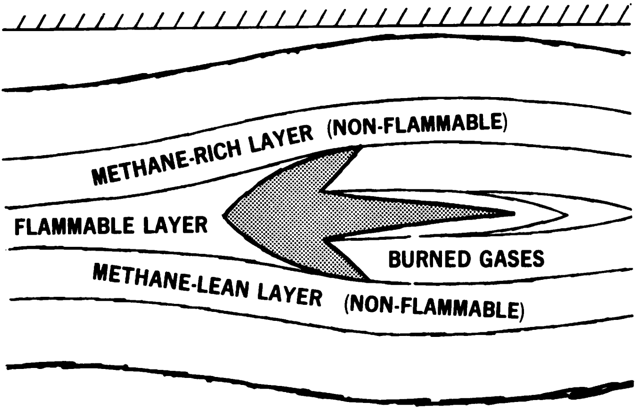
Carbon Dioxide (CO_2)

As noted previously, carbon dioxide is found in the air we breathe. However, it is also found in the soil, in coal, and in many rocks. It is formed by living animals, fires, and explosions. It is colorless with a slight acid taste when present in high concentrations. Carbon dioxide is normally considered to be inert, as it does not support combustion, and for this reason it is used to fight fires. However, carbon dioxide has several peculiar properties of interest to the miner. First, it is heavier than air and so it tends to flow into low-lying areas. Next, because of its role in the respiration process, the body can tolerate only small quantities in the surrounding air. For example, we find that even one-half of one percent (0.5 percent) carbon dioxide affects our breathing. Miners exposed to this concentration (0.5 percent or 5,000 ppm)[5] breathe a little deeper and faster; that is, their lung ventilation increases. When 3 percent carbon dioxide is present in the air, lung ventilation doubles. Ten percent carbon dioxide can be tolerated for only a few minutes even when an individual is at rest. (A mixture of 10 percent carbon dioxide and 90 percent air actually contains 18.9 percent oxygen.)

[5] Parts per million of the gas-air mixture.



In still air or where air velocity is slight, methane tends to rise to the roof of a tunnel or mine because it is lighter than air.



Air layers near the roof of a mine or tunnel which contain flammable methane are easily ignited. The flames propagate away from the ignition source into the flammable layer, and produce toxic products (burned gases).

Methane (CH_4) and Other Hydrocarbons

Methane is the most common of the flammable gases found in coal and any rock that contains combustible materials. This gas is colorless, odorless, tasteless, and tends to rise to the roof of a mine or tunnel because it is much lighter than air. Although it is nontoxic, methane dilutes the oxygen concentration when mixed with air, and thus acts as an asphyxiant.[6] Thousands of deaths have been attributed to the presence of this gas in the Nation's coal and metal/nonmetal mines in the past 60 years. These were due primarily to the fact that when mixed in the range of 5 to 15 volume percent in the air, methane forms flammable (explosive) mixtures. Mixtures in this composition range are easily ignited and propagate flames away from the ignition source (for example, an electric arc or an open flame). Such flames produce toxic products (including carbon monoxide) and oxygen-deficient atmospheres, and in many cases ignite flammable dust, timbers, coal, and other combustibles. For this reason, methane is not permitted to accumulate in mines.

30 CFR 75.323 Actions for excessive methane.

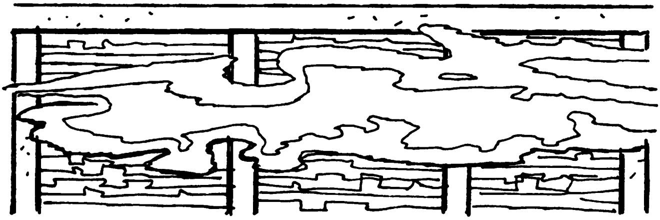
(c) Return Air Split. (1) When 1.0 percent or more methane is present in a return air split between the last working place on a working section and where that split of air meets another split of air, or the location at which the split is used to ventilate seals or worked-out areas, changes or adjustments shall be

[6] For example, a mixture of 1 cubic foot of air and 1 cubic foot of methane (in a closed space) produces a mixture with about 10.5 percent oxygen.

made to the ventilation system to reduce the concentration of methane in the return air to less than 1.0 percent.

Action to be taken in gassy noncoal mines depends on the classification of the mine.

Other hydrocarbon gases (for example, ethane and propane) are also found in some mines. These may come from adjacent oil and gas fields or from the coal and ore itself. However, they are typically found only in small (trace) amounts. Methane is conceded to be a component of coal, as well as salt, trona, and other minerals, having been formed along with carbon dioxide and water during the period in which the coal formed from various plants. The other hydrocarbons may have formed at a later stage. When present, they tend to decrease the lower limit of flammability slightly.



Carbon Monoxide (CO)

This gas is colorless, tasteless, odorless and slightly lighter than air. It is produced by fires and heated combustibles. However, certain coals tend to produce carbon monoxide slowly even at mine temperatures. This poses a health hazard because carbon monoxide combines more readily than oxygen with the hemoglobin of the blood. Once the hemoglobin combines with carbon monoxide, it cannot combine with oxygen and so limits the oxygen-carrying capacity of the blood. For example, 0.05 volume percent (500 ppm) carbon monoxide in air can be fatal in 3 hours. This concentration would block approximately one-half the hemoglobin in the blood (50 percent blood saturation). The rate at which carbon monoxide combines with blood depends on the exposure time, carbon monoxide concentration, and the activity of the exposed individual. For example, 5 percent blood saturation results when an individual at rest is exposed to 50 ppm[7] carbon monoxide for about 4 hours. However, the same blood saturation would result in about one hour if the individual were engaged in heavy work. A slight headache may develop at this concentration.

Carbon monoxide is also a flammable gas. It forms flammable mixtures with air over the range 12.5 to 74 volume percent of carbon monoxide. Such mixtures may be formed following a fire or an explosion.

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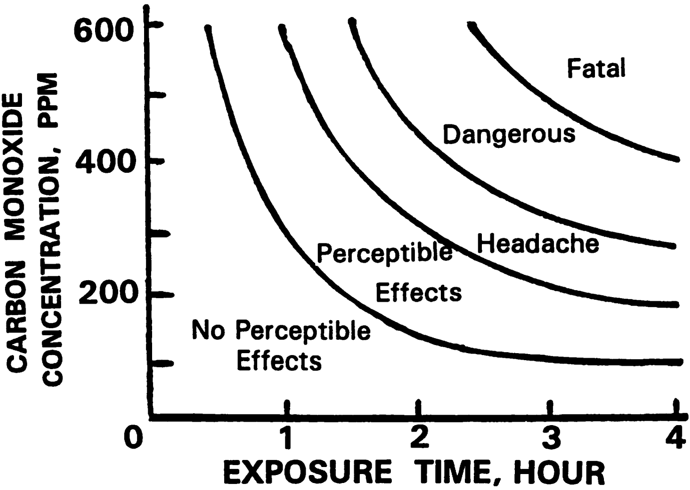
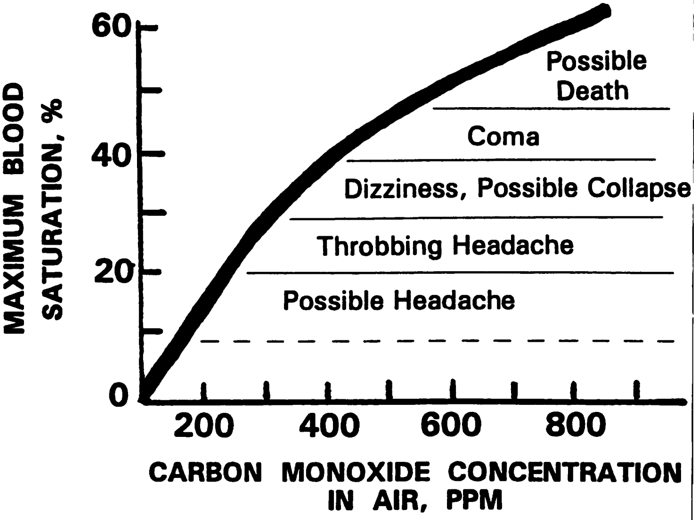
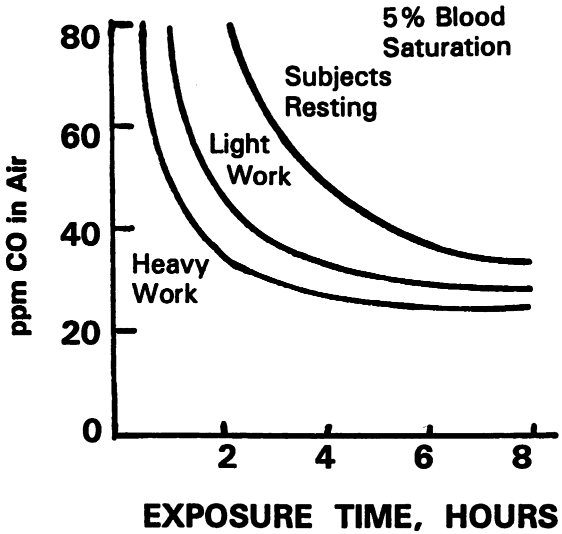
[7] This is the TLV (threshold limit value) or concentration limit for an 8-hour exposure.



Effects of carbon monoxide concentration and exposure time on humans.



Long-term effects of carbon monoxide in combination with the hemoglobin of the blood.



The effects of carbon monoxide concentration and activity on the time required to reach 5 percent blood saturation.

Oxides of Nitrogen

These gases are formed at high temperatures by diesel and gasoline engines, electrical discharges, and blasting operations. Most of them are toxic because they form very corrosive acids when mixed with moisture in the lungs. The threshold limit values of these gases are given as 25 ppm for nitric oxide (NO) and 5 ppm[8] for nitrogen dioxide (NO_2). While these are rather low values, these gases are readily detected and normally cause no difficulty as long as proper precautions are taken to dilute them with fresh air as they are formed.

Most chemists analyze air samples for nitrogen dioxide (NO_2), as it is the main oxide of interest even when in small concentrations. This gas is almost colorless in low (but toxic) concentrations and reddish-brown at higher concentrations. It is heavier than air, has the odor of blasting powder fumes, and is quite irritating to the throat when inhaled in even small concentrations.

[8] Ceiling value (maximum allowable concentration).

Sulfur Dioxide (SO_2)

This colorless, suffocating, irritating gas with a pungent sulfurous smell is much heavier than air. It is formed in fires that involve iron pyrites and when blasting certain sulfide ores. It has a rather low threshold limit value (5 parts per million of air) but, because it is an extreme irritant, it is very easy to detect. A person is not apt to remain for long in an atmosphere that contains this gas.

Hydrogen Sulfide (H_2S)

This is a colorless, toxic, flammable gas that has an odor of rotten eggs at low concentrations. It is also an irritant and is heavier than air. Unfortunately, prolonged exposure to hydrogen sulfide tends to dull the sense of smell. It has a threshold limit value of 10 parts per million of air and forms flammable mixtures (with air) over the concentration range of 4 to 44 volume percent. It is formed when blasting sulfide ores and occurs in some natural gas, oil, and coal fields.

Hydrogen (H_2)

This gas is not normally found in mine air unless a fire or explosion has occurred, although small quantities may be found near battery-charging stations. It is colorless, odorless, tasteless, and forms flammable mixtures with air over the range of 4 to 74 volume percent. As it is much lighter than air, it tends to rise to the roof of an enclosed area.

Gas Mixtures and Smoke

Many of the previously discussed gases are found as mixtures in mine environments. The mixtures have been given rather graphic names, such as **fire damp** (methane, and possibly trace amounts of other gases, and air); **afterdamp** (gaseous products and smoke produced by a fire or explosion, which include: carbon monoxide, carbon dioxide, water vapor, nitrogen, oxygen, hydrocarbons, and hydrogen); **blackdamp** (carbon dioxide and nitrogen in an oxygen-deficient atmosphere); and **rock gas** (nitrogen and carbon dioxide). Rock gas is hazardous because it creates an oxygen-deficient (asphyxiating) atmosphere. Normally, this mixture enters the mine from the adjacent rock strata at ordinary (atmospheric) pressures.

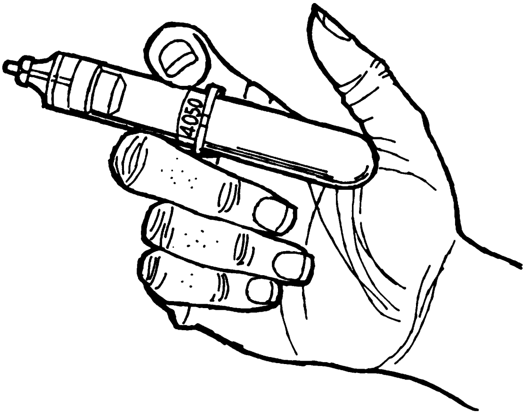
Smoke is made up of very small particles (soot and tars) suspended in the air. While smoke may irritate the nostrils and throat when inhaled, it is not normally considered to be an asphyxiating material, although it may be mixed with gases, such as carbon monoxide and other vapors produced by a fire that may be dangerous to inhale.

Smoke and numerous gases are produced by a fire.

ANALYSIS OF MINE GASES

Gas Samples

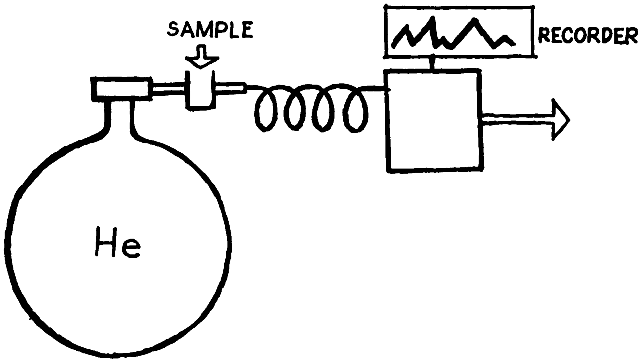
Thousands of gas samples are taken underground each year by MSHA inspectors as they inspect the Nation's mines. These samples are analyzed in portable detectors, described in the following sections, or in laboratories with precise instruments. The laboratory analyses are made on samples taken in evacuated bottles or in special syringes. While a number of procedures have been used over the years to analyze these gases, MSHA gas laboratories are now equipped with high precision analyzers (known as gas chromatographs).



MSHA inspectors use special evacuated syringes to take mine gas samples which are then evaluated in precision laboratory analyzers.

Chromatographs can determine the main components of a mine atmosphere (nitrogen, oxygen, carbon dioxide, and methane) in as little as three minutes, while a complete analysis may take 10 minutes.

Basically, a gas chromatograph consists of a small diameter tube through which helium (He) gas flows at a steady rate. The gas sample to be analyzed is injected into the helium as it enters the tube. The components in the gas sample travel through the tube at different speeds. Therefore, they separate and leave the tube at different times. Special detectors are used to determine the time required for each gas to exit and the amount of each component in the original mixture. If necessary, analyses can be checked by means of other independent instruments (such as the mass spectrometer and the infrared analyzer).



Schematic of a gas chromatograph. This equipment is used to analyze a mine air sample in as little as three minutes.

In general, most samples primarily contain air. Less than 5 percent have any appreciable quantity of a contaminant gas. Specially selected mine personnel monitor the mine atmosphere periodically with portable detectors and adjust the ventilation and mining rates to prevent the buildup of hazardous concentrations of methane and other contaminants.

Oxygen

Oxygen is the most important component of any atmosphere in which people work. A number of commercial analyzers, both laboratory and portable, are available to determine the oxygen concentration in mine air. In addition to the laboratory units noted previously, spot checks of the oxygen level in a mine can be made using a flame safety lamp, a liquid absorption device, a paramagnetic analyzer, or a special fuel cell that is sensitive to the oxygen concentration. The flame safety lamp is described in the next section (under methane). The other units are described in the following paragraphs. Oxygen is one of the few gases that is attracted by a magnetic field and is classed as a paramagnetic substance. Its effect on a magnetic field is measured directly on a scale calibrated to read the oxygen concentration.

Fuel (galvanic) cells, designed to measure the oxygen in the atmosphere, are manufactured by several different companies. Basically, these units use oxygen to affect the flow of current in an electric cell. They are calibrated to read the oxygen concentration directly. They were developed for use in the space program but now are widely used as portable oxygen indicators in the mines and various other areas.

The methane concentration must not exceed 1.0 volume percent in any working place when tested at a point not less than 12 inches from the roof, face, rib or floor.

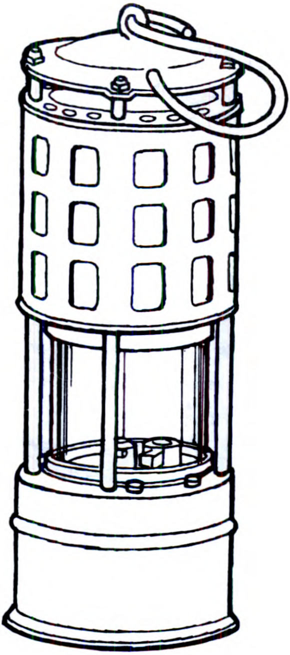
DETECTION AND IDENTIFICATION OF CONTAMINANT GASES

The air quality in underground mines must meet the standards prescribed in 30 CFR 75.321 and 75.322 (Coal) or 30 CFR 57.5001 (Metal and Nonmetal). In general, the threshold limit values (TLV) adopted by the American Conference of Governmental Industrial Hygienists must not be exceeded by any air contaminant. The TLV represents the maximum concentration of a gas or vapor that a person should be permitted to breathe in an 8-hour day (Appendix A). *"Tests for methane....shall be made at least 12 inches from the roof, face, ribs, and floor....When 1.0 percent or more methane is present in a working place or an intake air course....changes or adjustments shall be made....to reduce the concentration of methane to less than 1.0 percent." (30 CFR 75.323); and "Air in all active workings shall contain at least 19.5 volume percent oxygen."* (30 CFR 57.5015)

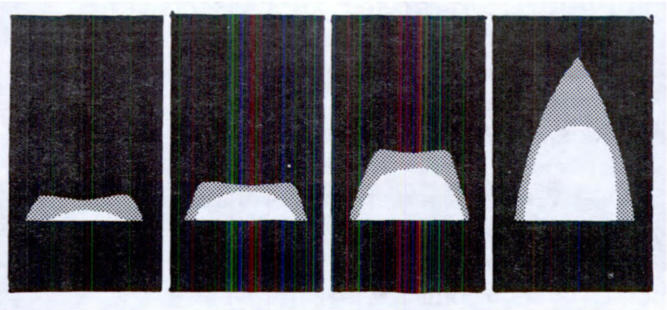
In evaluating a mine atmosphere, the detectors approved by the Mine Safety and Health Administration for underground use may be grouped into two broad categories: Those that depend on a chemical reaction and those that measure a physical property of the contaminant gas. Examples from each group are described as follows.

Methane

The flame safety lamp is probably the best known detector in the chemical reaction category. Present day safety lamps are refinements of those developed in England for illumination by Clanny, Davy, and Stephensen. They operate on the principle that the flame of an oil lamp increases in size when it burns in an atmosphere that contains methane.



The Koehler Permissible Flame Safety Lamp is used as an oxygen-deficiency indicator and a methane detector.



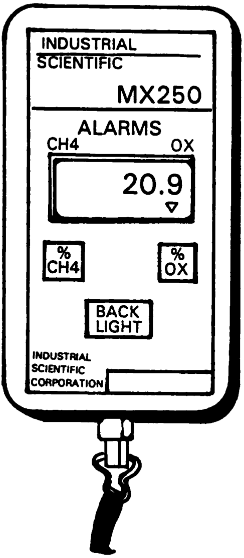
0% 1¼% 2% 3% CH_4

Effects of methane concentration on the flame of a Koehler Lamp.

Unfortunately, the flame decreases in size in an atmosphere that is deficient in oxygen and is extinguished when the oxygen concentration drops below about 16 volume percent. Further, when used underground, very few observers can reliably determine the concentration of methane in air at concentration levels below about 1¼ percent. Accordingly, the flame safety lamp should only be used as a supplemental methane testing device. *"Through November 15, 1995, a permissible flame safety lamp may be used to make tests for oxygen deficiency required by the regulations in this part. After November 15, 1995, an oxygen detector approved by MSHA shall be used for such tests and permissible flame safety lamps may only be used as a supplementary testing device."* (30 CFR 75.320(d)) Many operators use the flame safety lamp, in addition to hand-held instruments, to test for oxygen deficiency and methane. When used underground, the manufacturer's instructions must be followed precisely because many mine explosions have been attributed to the improper assembly and misuse of these lamps.

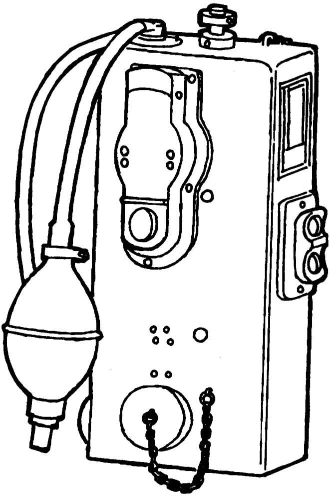
New hand-held gas detection instruments are replacing the flame safety lamp. Examples include the Industrial Scientific MX 250 methane and oxygen monitor which measures both gases, and the CMX 270 which measures methane, oxygen, and carbon monoxide.

Methane can be determined reliably at concentrations below 1.0 volume percent by use of any one of several commercially available, approved detectors. One of these draws a sample into a small cell where the methane is burned through contact with a heated wire. The amount of heat released in this manner is a direct measure of the amount of methane in the sample. An electric meter is calibrated to read the methane concentration



The Industrial Scientific Model MX250 is a hand-held, portable methane and oxygen detector.

The Riken Gas Indicator is a precision portable optical methane detector.

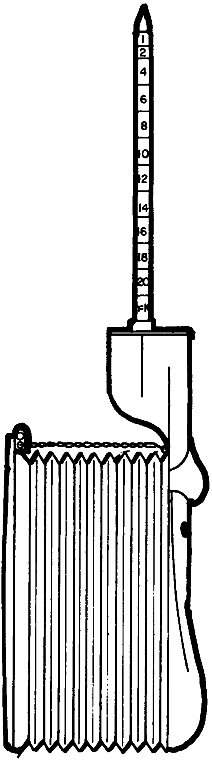


directly. Unfortunately, if other flammable gases are present, they also burn when in contact with the heated wire and, therefore, tend to produce erroneous (elevated) readings. When this occurs, a gas sample must be taken for a precise laboratory analysis. This is particularly true following a mine fire or an explosion when carbon monoxide, hydrogen, and oxygen-deficient atmospheres may be present.

For best results, each detector must be calibrated for the conditions under which it is to be used. Again, the manufacturer's recommendations must be followed for both the initial and subsequent calibrations, conditions of usage, and maintenance. The operator also must know the capabilities and limitations of each device used.

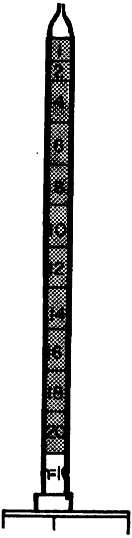
For methane concentrations above about 5 percent, most investigators prefer the use of thermal conductivity or optical detectors. (These concentrations are not encountered under ordinary circumstances.) The thermal conductivity detector works on the principle that a heated wire will cool at a different rate in methane (or a methane-air mixture) than it will in air. The rate of cooling is related to the concentration of methane. Again, if other gases are present they tend to produce erroneous results and a gas sample must be taken for a precise laboratory analysis.

The optical detector compares the speed of a beam of light through air with that through a sample drawn into a test cell. Light from a single source is split into two beams. One beam passes through a cell filled with air and the other through a cell into which a test sample has been drawn. The two beams are combined and produce interference fringes. The position of these fringes depends on the methane concentration. Again, while this is a very sensitive detector, it gives erroneous readings if contaminants other than methane are present in the test cell.



The Drager Multi Gas Detector is a portable length-of-stain indicator.

Close-up view of a carbon monoxide indicator tube exposed to 20 ppm carbon monoxide.



Carbon Monoxide

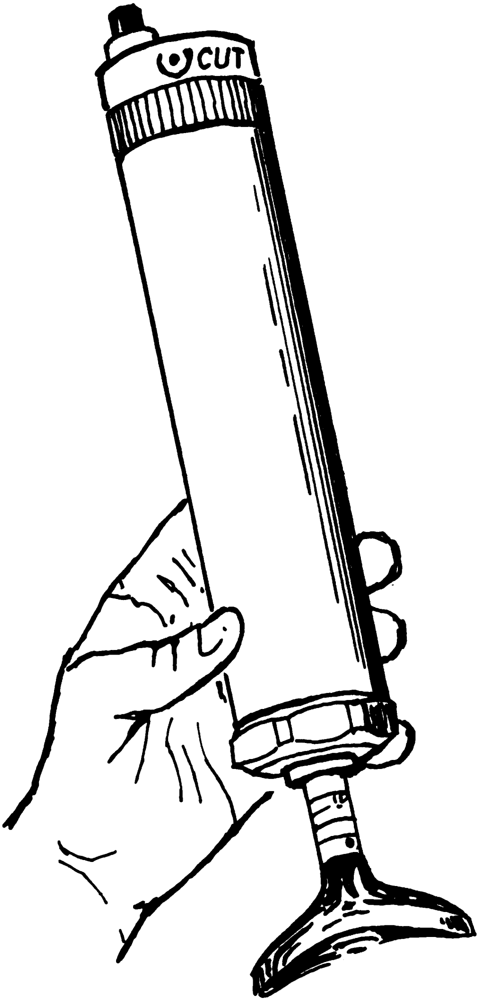
Several different types of portable detectors may be used to determine carbon monoxide. One type uses a detector tube with a chemical that changes color (from yellow to green) when exposed to carbon monoxide. The resultant color (shade of green) is an indication of the quantity of carbon monoxide in the test sample drawn through the chemical.

Another version of this type detector, currently the most common, relates the length of stain produced by the carbon monoxide contaminant drawn through a chemical substance in a glass tube.

Another type of detector uses an impregnated tape or tab that changes color when exposed to carbon monoxide. NEI-Bendix produces an alarm in which the color change is measured photoelectrically.

Still another type of detector measures the heat produced by the oxidation of carbon monoxide to carbon dioxide when it passes through a mixture of cupric and manganese oxides (Hopcalite). The amount of heat is proportional to the concentration of carbon monoxide.

New hand-held gas detectors, such as the CMX 270, simultaneously measure carbon monoxide, methane, and oxygen.



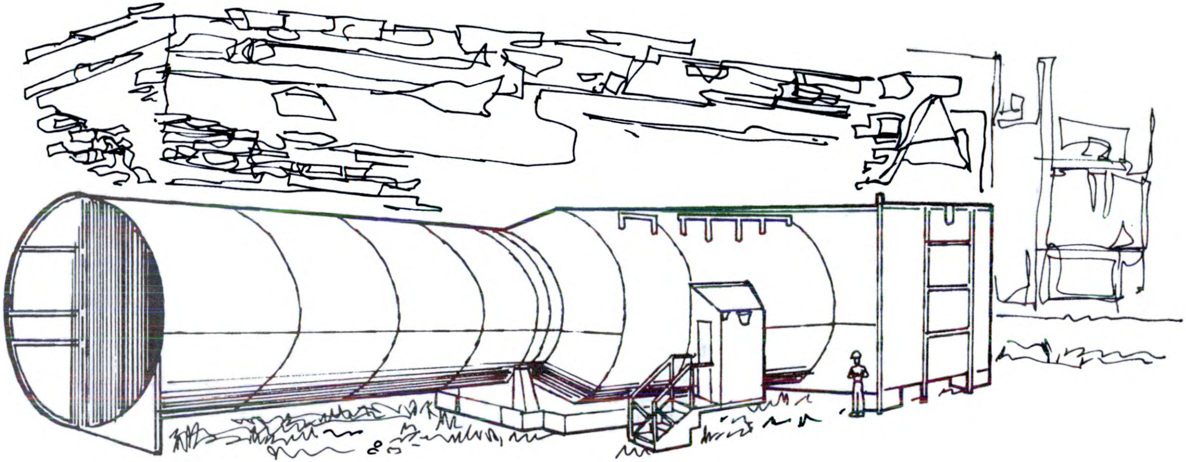
The MSA portable length-of-stain gas detector.

Oxides of Nitrogen; Sulfur Dioxide; Hydrogen Sulfide

Length of stain indicator tubes are available to detect oxides of nitrogen (NO_2), sulfur dioxide (SO_2), and hydrogen sulfide (H_2S). Commercial units are available from Bacharach, Drager, Mine Safety Appliances (MSA), and NEI-Bendix. Each is suitable for use at concentrations below the TLV of a specific contaminant gas. Unfortunately, the chemicals used in most of the detectors are also sensitive to more than one contaminant, and the results must be interpreted with care. The manufacturer's literature should be consulted before these units are used underground. The usable ranges for the NO_2, SO_2, and H_2S detector tubes marketed by the above manufacturers are given in Table 3.

Table 3 - Usable ranges of detector tubes for NO_2, SO_2, and H_2S

Manufacturer	Range, ppm		
	NO_2	SO_2	H_2S
Bacharach	1-50	1-2700	1-650
Drager	0.5-10	1-350	1-70,000
MSA	0.1-50	0-400	0-800
NEI-Bendix	1-1000	1-4000	1-3000



A mine ventilation fan system.

CONTROL OF MINE GASES

Normal Conditions

Increased quantities of air are normally the miner's primary defense against the accumulation of unwanted gases. Both the quality and quantity of air entering the working places are specified by law. A detailed description of the ventilation plans used in underground mines is given in a companion safety manual on ventilation.

Each operating underground mine is equipped with mechanical fans to move the air through the mine. These fans are inspected daily and the results are kept in a fan inspection book. In spite of this, a main fan may stop because of a malfunction or power failure. Should this occur, all persons must be withdrawn from the working sections. If the ventilation cannot be restored in a reasonable time, all persons must be removed from the entire mine as soon as possible.

Abnormal Conditions

An abnormal (gas) condition can be created underground in a number of ways. Chief among these is the interruption of the ventilation air; sudden outbursts of strata gases (methane, carbon dioxide, nitrogen); excessive mining rates; fires; and explosions. When an abnormal condition occurs, one or more emergency procedures must be initiated immediately to prevent the loss of life. These include: Improved ventilation; decreased mining rates; evacuation of miners; use of respiratory protection (self-contained breathing apparatus; carbon monoxide self-rescuer; gas mask; self-contained self-rescuer); use of underground shelters; erection of barricades (after fires or explosions). The first two are the responsibility of mine management. The others are the responsibility of the individual miner. For this reason, a miner must know the escape routes, when and how to use his/her self-rescuer and other available respiratory protection apparatus, the locations of underground shelters, and when, where, and how to build a barricade. These are discussed in greater detail in several other safety manuals published by MSHA (see inside back cover for list of safety manuals).

An SCSR is used after a fire or an explosion to escape through an atmosphere that contains carbon monoxide.

Abnormal conditions can often be prevented by removing methane from the coal and adjacent strata before mining occurs (pre-drainage); by the use of adequate air volumes (10 tons of air are used in many mines for each ton of coal that is removed, to dilute the methane adequately); by monitoring the contaminant gases periodically to detect significant changes in composition; by controlling mining rates; by drilling ahead in areas where gas outbursts are known to occur; by the use of approved equipment in an approved manner; and by the elimination of all ignition sources (including matches and cigarettes).

Some underground metal and nonmetal mines are classed as gassy and placed in different categories or subcategories, depending on the amount of methane liberated. Many of the same precautions listed above must be taken in these mines, such as diluting methane using approved air volumes, using approved and well maintained equipment, and by eliminating ignition sources.

There are also methane explosion hazards in surface mines and surface work areas of underground mines where coal is mined, handled, stored, processed, or used in other processes, such as in kilns for producing cement.

In short, all workers must be aware of the hazards associated with mine gases, and they must take all the necessary precautions to prevent the creation of abnormal conditions. However, when such conditions exist, they should be able to recognize them and take the necessary steps to protect themselves and their coworkers.

PROPERTIES OF MINE GASES

Gas	Symbol	Specific* gravity	Density** (lb/ft^3)	TLV*** (ppm)	Hazard
Air	-	1.0	0.075	-	(At elevated pressure)
Nitrogen	N_2	0.967	0.073	-	Simple asphyxiant
Oxygen	O_2	1.105	0.083	-	(At elevated pressure)
Carbon dioxide	CO_2	1.529	0.115	5000	Affects respiration
Methane	CH_4	0.554	0.042	-	Flammable and a simple asphyxiant
Carbon monoxide	CO	0.967	0.073	50	Very toxic

Nitric oxide	NO	1.036	0.078	25	Very toxic
Nitrogen dioxide	NO_2	1.589	0.119	5****	Very toxic
Sulfur dioxide	SO_2	2.264	0.170	5	Very toxic
Hydrogen sulfide	H_2S	1.191	0.089	10	Very toxic
Hydrogen	H_2	0.0695	0.0052	-	Flammable and a simple asphyxiant

* Ratio of density of gas to that of air at sea level and 70°F.

** Determined at sea level and 70°F.

*** Threshold Limit Value; average (time weighted) concentration for a daily 7 or 8 hour workday that will not produce an adverse affect in most workers.

**** Ceiling value (maximum allowable concentration).

GLOSSARY OF TERMS

Asphyxiate - To suffocate or choke.

Atmosphere - The gases that surround the earth or a unit of pressure equal to approximately 14.7 pounds per square inch.

CFR - Code of Federal Regulations.

Crosscut - A passageway that connects parallel entries or different seams in a mine.

Gas sample - An air or contaminated air volume taken underground for analysis.

Methane - A flammable gas found in most coal, and some metal/nonmetal mines; also known as marsh gas.

Mine - An opening or excavation in the earth from which minerals are removed.

Mine atmosphere - The air in an underground area used for mining.

Oxygen-deficient atmosphere - An atmosphere with an oxygen concentration below that found in normal air.

Room - An underground area in which coal is mined.

Self-rescuer - A device used to protect a miner against carbon monoxide and smoke in case of a mine fire or explosion.

Section - A part of the working area of the mine.

TLV - An average (time weighted) concentration of a substance to which an individual may be exposed 7 or 8 hours a day and 40 hours a week without an adverse effect.

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